CLAIMS:

1.   A diagnostic device for generating a characteristic impedance for an electrical winding having an input terminal and an output terminal, comprising:

a signal generator for applying an electrical signal having a frequency component to the input terminal of the electrical winding;

sensing means for detecting a magnitude and a phase of an output electrical signal at the output terminal of the electrical winding, the sensing means converting the magnitude and the phase of the output electrical signal into digital signals;

a processing means for setting parameters of the electrical signal and for receiving the digital signals, the processing means calculating the characteristic impedance with the digital signals and the parameters of the electrical signals corresponding to one frequency, based on a transmission line model of the electrical winding; and

storage means for storing the digital signals and the parameters of the electrical signal.

2.   The diagnostic device of claim 1, wherein the signal generator includes one of a function generator and a network analyzer for generating the electrical signal at the one frequency.

3.   The diagnostic device of claim 1, wherein the one frequency is a minimum frequency, the minimum frequency being selected corresponding to a maximum length of the electrical winding.

4.   The diagnostic device of claim 1, wherein the one frequency is at least about 500kHz

5.   The diagnostic device of claim 1, wherein the sensing means includes a high speed digital data recorder.

6.   The diagnostic device of claim 1, wherein the storage means includes a memory

5   device.

7.   The diagnostic device of claim 1, wherein the processing means includes
        a sequence generator for setting the parameters of the electrical signal for generation by the signal generator, the parameters including input voltage, input current

10   and the one frequency, and
        a calculation engine for receiving the input voltage, the input current, the one frequency, and the digital signals, the calculation engine being programmed with the transmission line model of the electrical winding for calculating the characteristic impedance.

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8.   The diagnostic device of claim 7, wherein the processing means further includes
        a controller core for receiving the characteristic impedance from the calculation engine, the controller core comparing the characteristic impedance with a base characteristic impedance to provide a corresponding difference value,

20   a fuzzy logic engine for receiving the corresponding difference value and for applying pre-programmed fuzzy logic to provide a corresponding text message, and
        a graphic engine for receiving the characteristic impedance and the base characteristic impedance for generating graphical plot information.

25   9.   The diagnostic device of claim 8, wherein the controller calculates an approximate displacement value of the electrical winding corresponding to the difference value.

10.   The diagnostic device of claim 8, further including a user interface for displaying the corresponding text message and for displaying the graphical plot information as a

30   graph of impedance versus frequency.

11. The diagnostic device of claim 1, wherein the transmission line model of the electrical winding is expressed by

$$V_k\, e^{-\gamma} + Z_c I_k\, e^{-\gamma} = Z_c I_m + R I_m\,;$$

$$V_k - Z_c I_k = R I_m e^{-\gamma} - Z_c I_m e^{-\gamma}\,;$$

for representing the circuit model of the electrical winding shown in Figure 6.

12. The diagnostic device of claim 11, wherein the transmission line model of the electrical winding is further expressed by

$$V_k - Z_c I_k = (V_f - Z_c I_f)e^{-\gamma_1}\,;$$

$$(V_k + Z_c I_k)e^{-\gamma_1} = V_f + Z_c I_f\,;$$

$$(I_m R - I_m Z_c)e^{-(\gamma+\gamma_1)} - \frac{V_f Z_c}{Z_x} = V_f - Z_c I_f\,;$$

$$(V_f + Z_c I_f - \frac{Z_c V_f}{Z_x})e^{-(\gamma+\gamma_1)} = I_m R + Z_c I_m\,;$$

where each expression represents a loop in the circuit model of the electrical winding shown in Figure 8.

13. The diagnostic device of claim 1, wherein the signal generator includes a recurrent surge generator for generating the electrical signal, the electrical signal including a train of pulses.

14. The diagnostic device of claim 13, wherein the train of pulses includes a train of square pulses.

15. The diagnostic device of claim 13, wherein the processing means includes a calculation engine for executing a Fourier transform algorithm to decompose the electrical signal and the digital signals into frequency components.

16.   The diagnostic device of claim 1, wherein the electrical winding includes a transformer winding housed in a tank.

5   17.   The diagnostic device of claim 16, wherein the transformer is on-line.

18.   A method for determining a characteristic impedance of an electrical winding, comprising:

      a)   applying an input signal having a frequency component to a first terminal

10   of the electrical winding;

      b)   measuring an output signal at a second terminal of the electrical winding;

      c)   storing the input signal data and the output signal data; and

      d)   calculating the characteristic impedance based on a transmission line model of the electrical winding with the input signal data and the output signal data

15   corresponding to one frequency.

19.   The method of claim 18, wherein the step of applying includes generating an analog signal having predetermined voltage and current values at the one frequency.

20   20.   The method of claim 18, wherein the one frequency is a minimum frequency, the minimum frequency being selected corresponding to a maximum length of the electrical winding.

21.   The method of claim 18, wherein the one frequency is at least about 500kHz.

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22.   The method of claim 18, wherein the step of applying includes generating a pulse train having predetermined voltage and current values.

23.   The method of claim 22, wherein the step of calculating includes executing a

30   Fourier transform algorithm for decomposing the input signal and the output signal into frequency components, where the frequency components include the one frequency.

24.   The method of claim 23, wherein the one frequency is at least about 500kHz.

25.   The method of claim 19, wherein steps a) to c) are repeated for a plurality of distinct frequencies before the step of calculating.

26.   The method of claim 25, wherein step of calculating includes calculating the characteristic impedance of the electrical winding at each of the plurality of distinct frequencies.

27.   The method of claim 18, wherein the electrical winding includes a transformer winding housed in a tank.

28.   The method of claim 27, wherein the transformer is on-line.

29.   A method for assessing a condition of an electrical winding, comprising:

    a)   obtaining a base characteristic impedance of the electrical winding at a first time;

    b)   storing the base characteristic impedance corresponding to the first time;

    c)   obtaining a current characteristic impedance of the electrical winding at a second time after the first time;

    d)   storing the current characteristic impedance corresponding to the second time;

    e)   calculating a difference value between the current characteristic impedance and the base characteristic impedance; and

    f)   calculating an approximate winding displacement from the difference value.

30.   The method of claim 29, further including a step of calculating an approximate fault impedance of the electrical winding at the second time.

31.   The method of claim 29, wherein the step of obtaining the base characteristic impedance includes calculating the base characteristic impedance from:

$$Zc = 120\pi\sqrt{\frac{\mu}{\varepsilon}}\frac{N}{h}\frac{b}{1+b/d} \quad \Omega$$

where:

    Zc is the base characteristic impedance,

    μ is a magnetic permeability of the electrical winding material

    ε is a dielectric constant of insulation material

    N is a total number of the turns of the electrical winding

    h is an axial length of the electrical winding

    b is an insulating distance between the electrical winding and a core of a transformer

    d is an insulating distance between the electrical winding and a tank of the transformer

    v_0 is the velocity of light in a vacuum, 300m/us.

32.   The method of claim 29, wherein the step of obtaining the base characteristic impedance includes

    a)   applying an input signal having a frequency component to a first terminal of the electrical winding;

    b)   measuring an output signal at a second terminal of the electrical winding;

    c)   storing the input signal data and the output signal data; and

    d)   calculating the base characteristic impedance from a transmission line model of the electrical winding with the input signal data and the output signal data corresponding to one frequency.

33.   The method of claim 32, wherein steps a) to d) are repeated for a plurality of frequencies.

34.   The method of claim 32, wherein the step of obtaining the current characteristic impedance includes

    e)   applying the input signal having the frequency component to the first terminal of the electrical winding;

f)   measuring a second output signal at the second terminal of the electrical winding;

g)   storing the input signal data and the second output signal data; and,

h)   calculating the current characteristic impedance from the transmission line model of the electrical winding with the input signal data and the second output signal data corresponding to the one frequency.

35.   The method of claim 34, wherein steps e) to h) are repeated for the plurality of frequencies.